MICHIGAN DEPARTMENT OF ENVIRONMENT, GREAT LAKES, AND ENERGY
WATER RESOURCES DIVISION
STAFF REPORT

A CAGED FISH STUDY
OF THE PINE, TITTABAWASSEE, AND SAGINAW RIVERS
SEPTEMBER 20-OCTOBER 18, 2017

BACKGROUND

A caged fish study involves holding hatchery reared fish in small pens placed at selected sites, most often in a river. These studies are a useful water quality monitoring tool because the test fish are exposed to the water column under relatively controlled conditions. Bioaccumulative contaminants such as dioxins and polychlorinated biphenyls (PCB) accumulate in the caged fish at levels that are generally orders of magnitude above the concentrations in the ambient water. The relatively high concentrations in the tissue of the exposed fish are often easier and cheaper to measure than the low concentrations typically found in the ambient water.

Results from caged fish studies are not intended to be a substitute for the analysis of wild caught fish and are not used to evaluate the need for consumption advisories. Caged fish are only exposed for a short period (generally 28 days) and ideally only accumulate contaminants by absorption through the gills and skin. In contrast, wild fish will absorb contaminants at generally higher rates, primarily through their diet.

Results from these studies are used to evaluate spatial and temporal differences in water quality. More specifically, if the concentration measured at a given site is significantly higher than a site further upstream we would conclude that there is a source of the contaminant of interest between the two sites. Temporal changes in waterborne bioaccumulative contaminants can be assessed by sampling a specific site or set of sites at appropriate intervals.

Accumulation of contaminants by caged fish is a function of the amount of water the fish are exposed to over the testing period. This will be affected by the placement of cages in the stream as well as by changes in river discharge. For most studies it is assumed exposure differences between sampling sites are minimal for a given sampling event. Differences in river discharge can be a significant factor between sampling years however and needs to be considered when evaluating temporal trends.

An intensive caged fish study was conducted in 2002 by the Michigan Department of Environment, Great Lakes, and Energy (EGLE) (previously known as the Michigan Department of Environmental Quality), Water Resources Division (WRD), (Day and Bohr, 2005) throughout the Saginaw River watershed, including sampling sites on the Pine River in Gratiot and Midland Counties, the Tittabawassee River in Midland and Saginaw Counties, and the Saginaw River in Saginaw and Bay Counties. Additional smaller scale caged fish studies were conducted by EGLE, WRD, on the Pine River in 2007 and on the lower Saginaw River in 2005 (Bohr, 2008).

This report summarizes the results of a 2017 caged fish study conducted by EGLE, WRD, in response to several requests:

- The Pine River Citizens Task Force requested an updated study of the Pine River in the vicinity of St. Louis.
- EGLE, Materials Management Division, Hazardous Waste Section, requested a caged fish study of the Tittabawassee River to determine the effectiveness of recently completed sediment remediation on three reaches of the river downstream of Midland.
- Lastly, the Saginaw River and Bay Natural Resource Damage Assessment and Restoration Trustee Council requested a study to help evaluate the effectiveness of Saginaw River sediment remediation work completed in 2001.

Pine River

The Pine River in the vicinity of St. Louis, Michigan, including the St. Louis impoundment, was severely contaminated with dichlorodiphenyl trichlorethane (DDT) and other compounds due to a legacy of the Michigan Chemical/Velsicol Chemical Company that had operations on the impoundment until 1978. A significant sediment removal project in the St. Louis impoundment was completed in 2006 by the United States Environmental Protection Agency (USEPA) with support from EGLE. The 2007 post-remediation caged fish study conducted by EGLE indicated that surface water concentrations of DDT in the Pine River had not declined since the previous 2002 caged fish study, although river conditions differed significantly between the two study years and may have affected the results. One objective of the current 2017 study was to determine if conditions in the impoundment have improved since the 2006 sediment remediation project.

Tittabawassee River

The Dow Chemical facility in Midland started operations in 1897. Previous waste disposal practices at the facility resulted in discharged liquid wastes containing dioxin into the Tittabawassee River. The 2002 caged fish study conducted by EGLE, WRD, included deployments at five sites on the Tittabawassee River downstream of the Midland Dam and three sites on the Saginaw River. Findings from the 2002 study included an increase in the surface water concentration of dioxins and furans from upstream to downstream in the Tittabawassee River followed by a reduced concentration in the Saginaw River due to dilution by the addition of discharge from the Shiawassee River and other tributaries (Day and Bohr, 2005).

Dow Chemical has completed remediation projects on the Tittabawassee River between Midland and Freeland from near Gordonville Road to near State Road (highlighted in Figure 3). Remediation work included sediment removals, sediment capping, bank removals, bank stabilization, and floodplain excavations in different areas along the stretch shown.

Three of the 2002 Tittabawassee River caged fish sampling sites were sampled again in 2017 allowing a comparison of relative concentrations both spatially and temporally.

Saginaw River

The Saginaw River and Saginaw Bay together are designated as a Great Lakes Area of Concern by the International Joint Commission due, in part, to high levels of PCBs found in sediments and fish. In addition, the Saginaw River and Saginaw Bay are included on Michigan's

Section 303(d) list of water bodies not attaining the fish consumption designated use requirement of the Water Quality Standards, also partly due to elevated PCBs in the water column, fish tissue, or both. A remediation project was conducted in 2000/2001 during which an estimated 342,433 cubic yards of contaminated sediments were removed from several areas of the lower Saginaw River in Bay City, from near the Truman Parkway Bridge downstream to near Wilder Road. The remediated areas represented the most severely contaminated sites in the lower Saginaw River.

A 2005 caged fish study conducted by the WRD on the Saginaw River suggested an overall decline in water column PCB concentrations at the river mouth post-remediation but also indicated the continued presence of PCB inputs from the remediated river reach (Bohr, 2008). The 2017 caged fish study provides additional data necessary to evaluate the effectiveness of the 2000/2001 remediation work.

SUMMARY

1. Caged fish were deployed for 28 days between September 20 and October 17, 2017, to monitor water quality in the Pine River (4 sites), Tittabawassee River (4 sites), Saginaw River (6 sites), and Saginaw Bay (1 site).
2. Total PCB and total DDT concentrations were analyzed in all samples. Dioxin toxic equivalence (TEQ), including dioxin-like PCB congeners, was analyzed in samples from selected sites in the Saginaw and Tittabawassee Rivers.
3. The DDT concentration measured in the Pine River downstream of the St. Louis dam in 2017 was significantly lower than had been measured in 2007 indicating that the 2006 sediment remediation effort removed a significant amount of the contamination from the St. Louis impoundment.
4. Although PCBs remain in the Saginaw River, concentrations appeared to decline significantly between 2005 and 2017. Differences in the river discharge between the two sampling periods may explain part of the observed difference in concentrations.
5. Lipid normalized dioxin TEQ concentrations were lower in the 2017 samples as compared to the 2002 samples from the Freeland Road and Center Road sites on the Tittabawassee River.
6. Dioxin-like (coplanar) PCBs did not contribute significantly to the dioxin TEQ.

METHODS

EGLE, WRD, personnel conducted the caged fish study following Procedure WRD-SWAS-010. Cages were deployed on September 20 and retrieved on October 18, 2017. One stainless steel cage was placed at each of 15 sites in the Pine, Tittabawassee, and Saginaw Rivers (Table 1; Figures 1-4). Channel catfish were used as the test species in the caged fish study. The fish were purchased from Stoney Creek Fisheries & Equipment (Grant, Michigan) and ranged from 6 to 9 inches in total length. Control (day-0) samples were obtained at the beginning of the test period by randomly selecting a subset of 20 channel catfish and combining them into 4 composite samples of whole fish. The remaining channel catfish were divided evenly between the test sites with approximately 20 fish per cage. After 28 days the fish were removed from the cages and divided into 4 composite samples per cage. Two composite samples from each of sample sites 13 and 14 were used to represent the Saginaw River mouth. Each fish was weighed to the nearest gram and measured to the nearest millimeter. Composite sample

weights ranged from 156 to 309 grams and averaged 214 grams. Composite samples were wrapped in aluminum foil, labeled, and frozen until analysis.

Samples were analyzed by the Michigan Department of Health and Human Services, Analytical Chemistry Laboratory. All samples were analyzed for total PCBs (83 congeners) and other halogenated organics (Table 2) as well as for lipid content.

Total DDT concentrations were calculated by summing concentrations of the para, para' and ortho, para' forms of DDT, dichlorodiphenyldichloroethylene (DDE), and 1,1-bis(4-chlorphenyl)-2,2-dichloroethane (DDD). Individual chemicals below the reporting level (1 microgram per kilogram [µg/kg]) were assigned a concentration equal to 0 for the purpose of calculating a total DDT concentration. If all 6 components were below the reporting level, then the total DDT concentration was reported as less than the lowest reporting level of the metabolites.

Table 1. Sites on the Pine, Tittabawassee, and Saginaw Rivers sampled with caged fish in 2017.

Water Body	Site #	Location	Description	Latitude	Longitude
Pine River	1	Cheesman Road	upstream reference site	43.400506	-84.615692
	2	M-46	St. Louis impoundment upstream Velsicol site	43.407752	-84.618905
	3	Mill Street	between Velsicol site and dam	43.413458	-84.60882
	4	Downstream St. Louis dam	downstream Velsicol site	43.411034	-84.607430
Tittabawassee River	5	South Poseyville Road	upstream reference site	43.610196	-84.243929
	6	Smith Crossing Road	downstream Reach 2	43.56425	-84.187288
	7	Freeland Road	downstream Reach 3	43.525098	-84.125101
	8	Center Road	near river mouth	43.393585	-84.015104
Saginaw River	9	7th Street (Veterans Memorial) Bridge	upstream of remediation area	43.59625	-83.89351
	10	Truman Parkway Bridge	upstream remediation areas 2 and 3	43.61326	-83.87292
	11	Bay City RR Bridge	downstream remediation areas 2 and 3	43.61322	-83.85701
	12	Wilder Road/Bay Harbor Marine	downstream remediation areas 4 and 5	43.6229	-83.8411
	13	River mouth, left bank*	evaluate full river	43.6442	-83.8502
	14	River mouth, right bank*		43.6410	-83.8466
Saginaw Bay	15	Shelter/Channel Island	for comparison with river mouth	43.67084	-83.83151

* - 2 composite samples from each site

Table 2. Standard suite of contaminants assayed in caged fish samples.

Hexachlorobenzene	Heptachlor Epoxide	Heptachlorostyrene
gamma-BHC (Lindane)	Mercury	Pentachlorostyrene
Aldrin	Oxychlordane	Heptachlor
Dieldrin	*gamma*-Chlordane	Terphenyl
4,4'-DDE	*trans*-Nonachlor	Apparent Toxaphene
4,4'-DDD	*alpha*-Chlordane	Mirex
4,4'-DDT	*cis*-Nonachlor	PBB (FF-1, BP-6)
2,4'-DDD	Octachlorostyrene	Total PCB (congener method)
2,4'-DDT	Hexachlorostyrene	

Total PCB concentrations were estimated by summing the concentrations of the 83 PCB congeners. Individual congeners with concentrations below the analytical quantitation level were assigned a concentration equal to 0 for the purpose of calculating the total PCB concentration. Also, congener analyses that did not meet retention time criteria or were subject to analytical interference were assigned a concentration equal to 0 for the purpose of calculating a total PCB concentration.

Analyses of chlorinated dibenzo-p-dioxin, dibenzofuran (Table 3a), and coplanar PCB congeners (Table 3b) were performed on the Tittabawassee River, Saginaw River, and the day-0 control samples. Total 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) TEQ was calculated for those samples using toxic equivalency factors developed by the World Health Organization and approved by the USEPA (2010). The concentrations of individual dioxin, furan, and dioxin-like PCB congeners in a sample were multiplied by chemical-specific toxic equivalency factors and the resulting products summed to calculate a TCDD TEQ concentration. Individual congener concentrations less than the analytical detection level were assigned a value of 0 for the purpose of calculating the dioxin TEQ. In order to evaluate the impact of PCBs on the TEQ calculations were made both with and without the coplanar PCB congeners.

DDT, PCBs, and dioxins are strongly lipophilic and total concentrations in tissue samples have been shown to be highly influenced by the concentration of fat in the sample. Therefore, for statistical comparisons, the concentrations of these compounds were lipid-normalized by dividing total DDT, total PCB, and TEQ concentrations by the lipid concentration and presented as units of contaminant per unit of lipid.

Net uptake of lipid-normalized total DDT, total PCB, and TEQ was calculated based on the relationship between the concentration in the control day-0 fish samples and the concentration in the deployed caged fish samples. Analysis of variance (lipid-normalized total DDT, total PCB, or TEQ versus sample site) was used to determine if significant site effects existed. Tukey's pairwise comparison was used to determine if concentrations in samples from each test site were significantly different than the control samples. When the sample site concentration was not significantly different than the day-0 control samples the site was determined to have no quantifiable uptake (NQU).

Where uptake was quantified the net uptake was calculated by subtracting the average lipid-normalized total DDT, total PCB, or TEQ concentration in the control samples from the concentrations in each of the test samples.

Statistical comparisons were considered significant at $p \leq 0.05$.

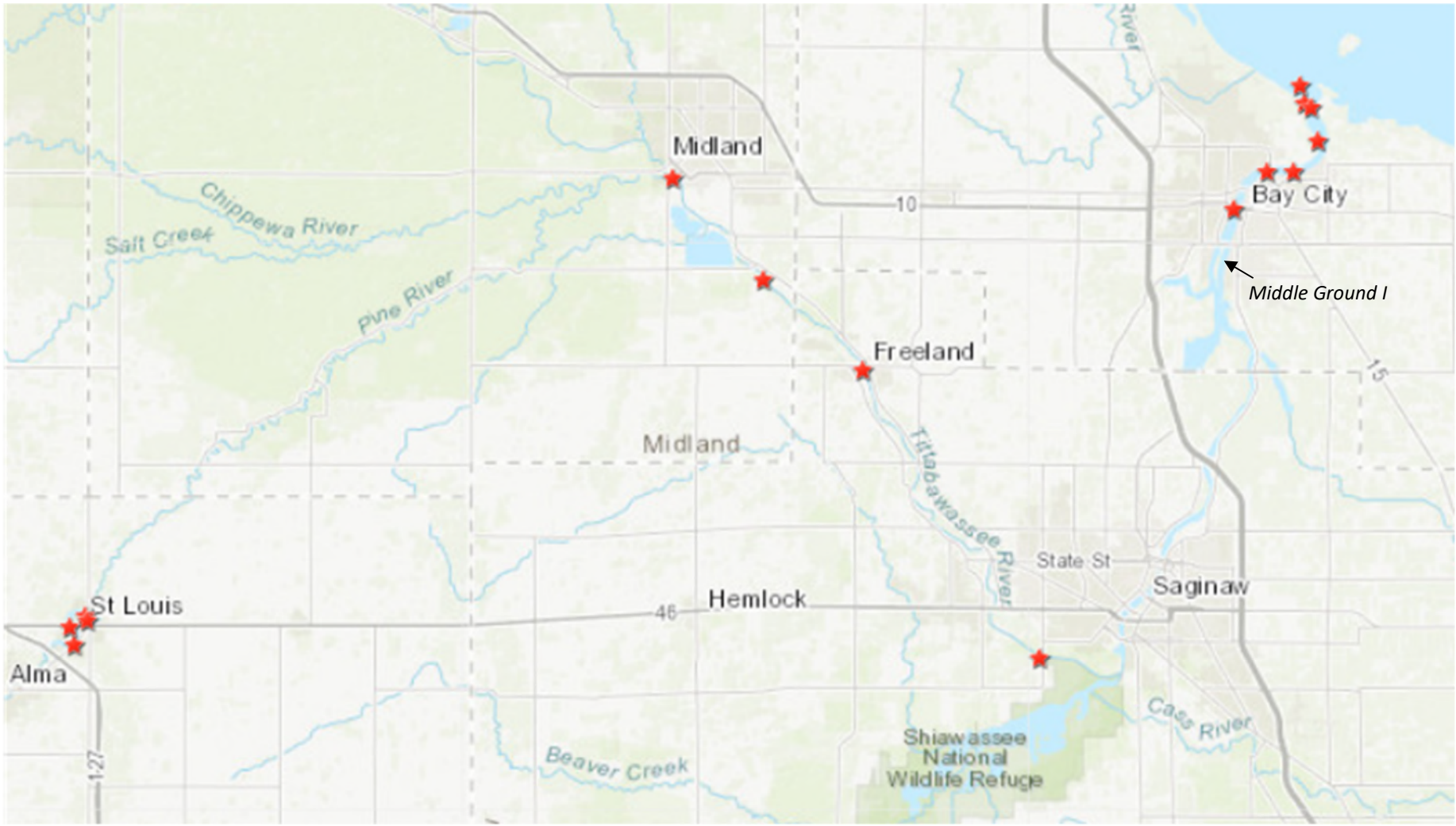

Figure 1. Overview of the Pine, Tittabawassee, and Saginaw Rivers. Stars indicate 2017 caged fish deployment locations.

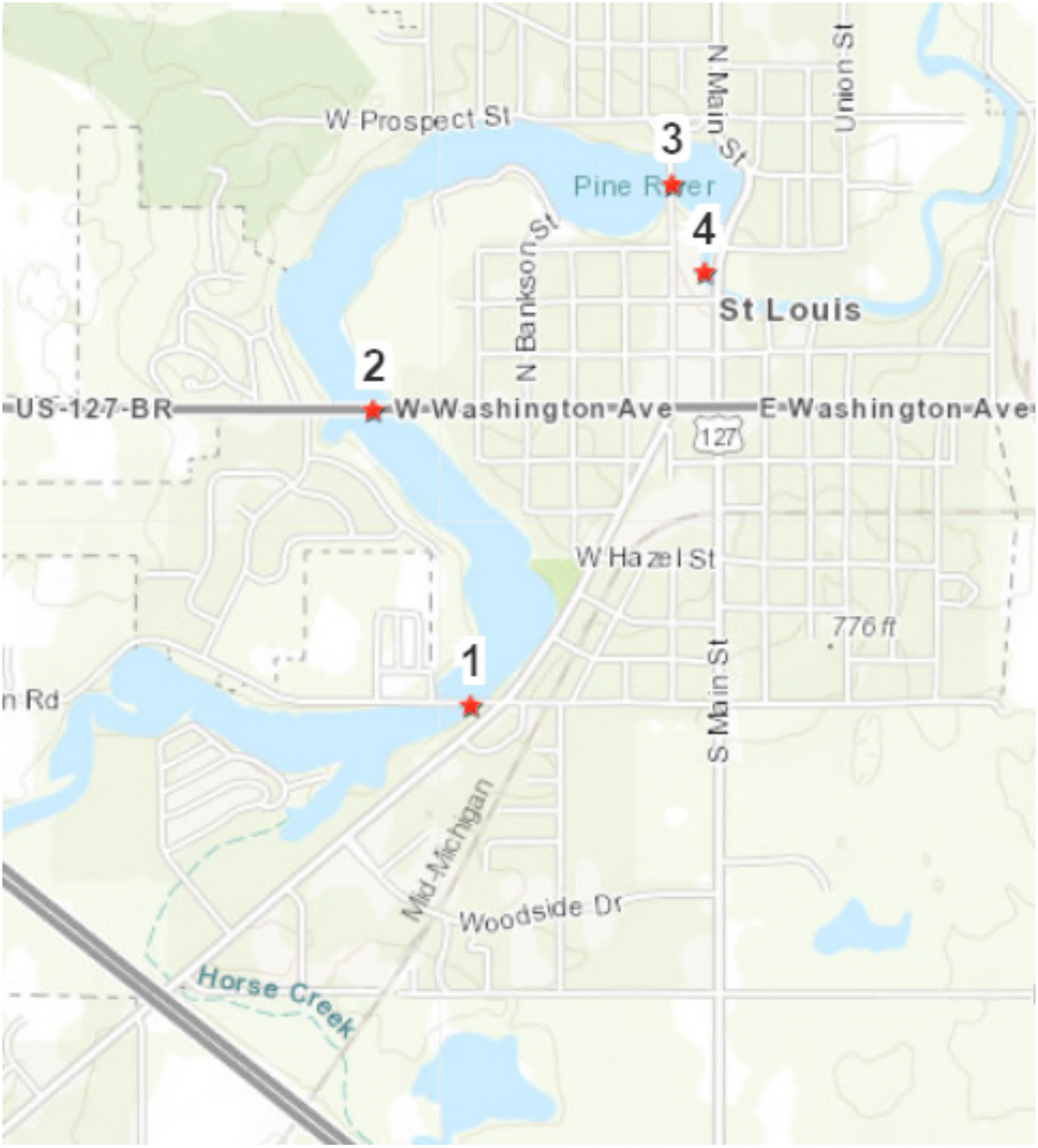

Figure 2. Map of the Pine River in the vicinity of St. Louis, Michigan. Stars indicate 2017 caged fish deployment locations. Numbers in white boxes indicate site numbers from Table 1.

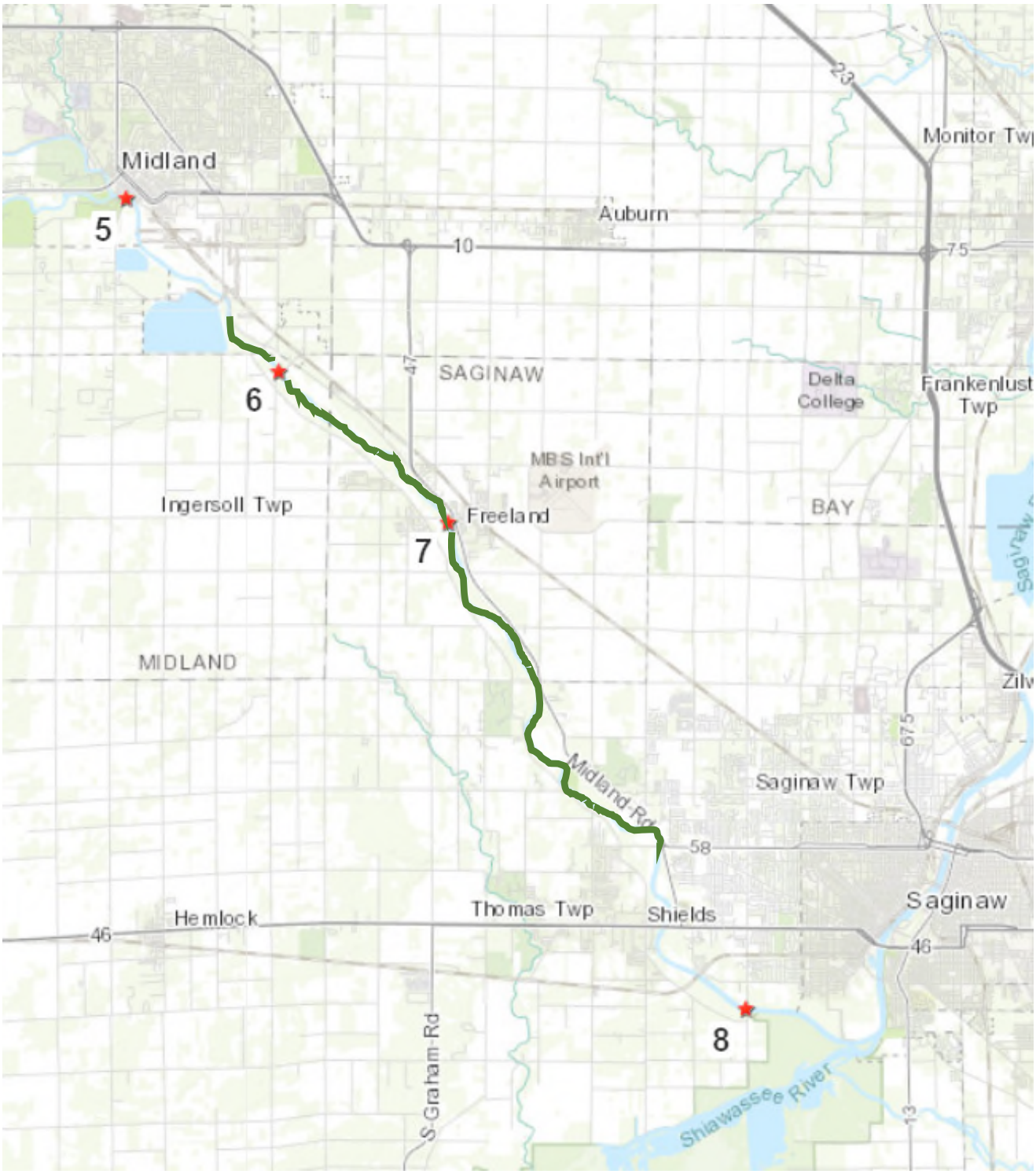

Figure 3. Map of the Tittabawassee River from Midland, Michigan, to the confluence with the Saginaw River. Stars indicate 2017 caged fish deployment locations. Numbers in white boxes indicate site numbers from Table 1. Green shaded river reach approximates area of previous remediation work.

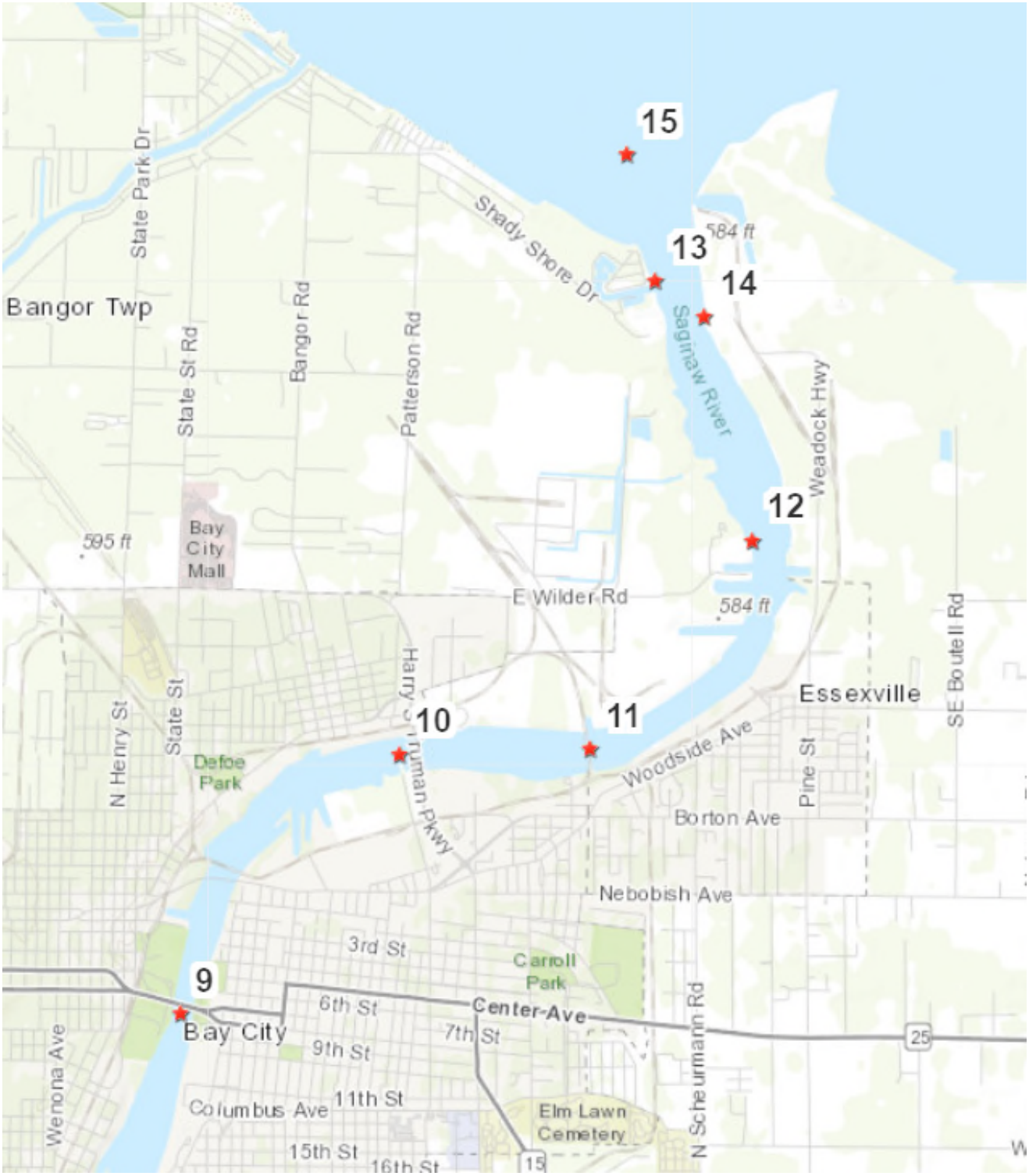

Figure 4. Map of the Saginaw River in the vicinity of Bay City, Michigan. Stars indicate 2017 caged fish deployment locations. Numbers in white boxes indicate site numbers from Table 1.

Table 3a. Chlorinated dibenzo-p-dioxin (Dioxins) and chlorinated dibenzofuran (Furans) congeners quantitated in selected caged fish samples.

Dioxins	Furans
2,3,7,8-Tetrachlorodibenzo-p-dioxin (TCDD)	2,3,7,8-Tetrachlorodibenzofuran (TCDF)
1,2,3,7,8-Pentachlorodibenzo-p-dioxin (PCDD)	1,2,3,7,8-Pentachlorodibenzofuran (PCDF)
1,2,3,4,7,8-Hexachlorodibenzo-p-dioxin (HxCDD)	2,3,4,7,8-PCDF
1,2,3,6,7,8-HxCDD	1,2,3,4,7,8-Hexachlorodibenzofuran (HxCDF)
1,2,3,7,8,9-HxCDD	1,2,3,6,7,8-HxCDF
1,2,3,4,6,7,8-Heptachlorodibenzo-p-dioxin (HpCDD)	1,2,3,7,8,9-HxCDF
1,2,3,4,6,7,8,9,-Octachlorodibenzo-p-dioxin (OCDD)	1,2,3,4,6,7,8-Heptachlorodibenzofuran (HpCDF)
	1,2,3,4,7,8,9-HpCDF
	1,2,3,4,6,7,8,9-Octachlorodibenzofuran (OCDF)

Table 3b. Coplanar PCB congeners analyzed quantitated in selected caged fish samples.

BZ#	Structure	BZ#	Structure
	TETRACHLOROBIPHENYLS		HEXACHLOROBIPHENYLS
77	3,3'4,4'	156	2,3,3',4,4',5
81	3,4,4',5	157	2,3,3',4,4',5'
	PENTACHLOROBIPHENYLS	167	2,3',4,4',5,5'
105	2,3,3',4,4'	169	3,3',4,4',5,5'
114	2,3,4,4',5		HEPTACHLOROBIPHENYLS
118	2,3',4,4',5	189	2,3,3',4,4',5,5'
123	2',3,4,4',5		
126	3,3',4,4',5		

BZ# = identification numbers adopted by the International Union of Pure and Applied Chemists (IUPAC).

RESULTS AND DISCUSSION

DDT

Lipid normalized concentrations of total DDT in caged fish samples were quantifiable in samples from 6 of the 15 sites sampled in 2017 (Table 4). The DDT concentrations in the caged fish from the St. Louis impoundment of the Pine River upstream of the Velsicol site at Cheesman Road and M-46 were not statistically different than the day-0 control samples (no quantifiable uptake).

Table 4. Net uptake of lipid normalized total DDT (µg/g [parts per million (ppm)]). NQU = no quantifiable uptake.

Water Body	Site Location	Sample Year				
		1999	2000	2002	2007	2017
Pine River	Cheesman Road					NQU
Pine River	M-46	0.02	0.01	0.009		NQU
Pine River	Mill Street		0.28			0.006
Pine River	Downstream Dam	0.73	0.68	0.2	0.68	0.03
Tittabawassee River	Poseyville Road					NQU
Tittabawassee River	Smiths Crossing		0.04	0.02		0.002
Tittabawassee River	Freeland Road			0.001		NQU
Tittabawassee River	Center Road			0.002		0.003
Saginaw River	7th Street					0.006
Saginaw River	Truman Parkway					NQU
Saginaw River	D & M RR					NQU
Saginaw River	Wilder Road					0.003
Saginaw River	River Mouth			0.006		NQU
Saginaw Bay	Gull Island					NQU

The net uptake of DDT in caged fish at Mill Street, downstream of the Velsicol site in the Pine River, was quantifiable but low (0.006 µg/g; Table 4). The 0.030 µg/g DDT concentration in caged fish downstream of the St. Louis dam was significantly higher than the Mill Street location (Table 4; Figure 5). Due to safety concerns, contaminated sediment at the upstream face of the dam could not be removed during the 2006 remediation effort. The elevated DDT concentrations at the sampling site downstream of the dam is likely a reflection of residual contaminated sediment at the dam.

The DDT concentration measured in the 2017 caged fish downstream of the St. Louis impoundment of the Pine River was significantly lower than had been measured in the 2007 caged fish study (Figure 5). This indicates that the 2006 sediment remediation effort was successful in removing the bulk of the DDT contamination from the St. Louis impoundment of the Pine River.

Table 5. Net uptake of lipid normalized total PCB (nanograms per gram [ng/g] [parts per billion (ppb)]). NQU = no quantifiable uptake.

Water Body	Site Location	Sample Year		
		2002	2005	2017
Tittabawassee River	Center Road	4		NQU
Saginaw River	7th Street Bridge		44	8
Saginaw River	Truman Pkwy Bridge		52	14
Saginaw River	Detroit & Mack RR		44	9
Saginaw River	Wilder Road		83	16
Saginaw River	River Mouth	65	77	9
Saginaw Bay	Gull Island		44	1

PCBs

Lipid normalized concentrations of total PCBs in caged fish samples from the 4 Pine River sites and from the 4 Tittabawassee River sites were not statistically different than the Day-0 control samples (Table 5; Figure 6).

In contrast, all caged fish samples from the Saginaw River sites had quantifiable levels of lipid normalized total PCBs. Although the concentrations were nominally different at the 5 Saginaw River sites (Table 5; Figures 7 and 8), the concentrations were not statistically different from one another.

The caged fish samples collected from the Gull Island site in Saginaw Bay (at the outlet of the Saginaw River) did not have quantifiable concentrations of lipid normalized total PCBs. These samples were exposed to open waters of the bay as well as to discharge from the river. Presumably, dilution by the relatively less PCB contaminated bay water explains the lower concentrations in the Gull Island caged fish.

Lipid normalized total PCB concentrations declined significantly between 2005 and 2017 at all Saginaw River caged fish sites (Table 5; Figure 9) and at similar rates. The decline between 2005 and 2017 across all Saginaw River sites averaged 81% and ranged from 73% to 88%. The relative concentrations between sites had a similar pattern in both years. The difference in concentrations between the 2 sampling years may be explained, in part, by the difference in river discharge. The daily mean river discharge measured at the United States Geological Survey station in the city of Saginaw was significantly higher during the 2005 caged fish sampling event as compared to the 2017 caged fish event (Figures 10a and 10b). Since the concentration of contaminants accumulated by caged fish is a function of the amount of water the fish are exposed to, the actual between year difference in surface water concentrations may be less.

The nominal differences between Saginaw River sampling sites in the 2017 caged fish study suggest that there are residual low levels of contaminated sediment upstream of the Wilder Road site. This is not surprising; it was not expected that dredging would be able to remove 100% of the contamination.

Dioxin TEQ

Dioxin TEQ was measurable at all of the Tittabawassee River and Saginaw River sampling sites as well as at the Gull Island site in Saginaw Bay (Table 6; Figure 11). The TEQ due to dioxin and furan congeners (calculated without coplanar PCBs) in the Tittabawassee River at the Freeland Road and Center Road caged fish sites in 2017 was significantly lower than the concentrations measured in 2002. The total Tittabawassee River discharge was somewhat higher during the 2002 sampling event than during the 2017 event (Figures 12a and 12b), but the difference probably did not affect the comparison significantly.

Table 6. Net uptake of lipid normalized dioxin TEQ (nanograms per kilogram (ng/kg [parts per trillion (ppt)]). TEQ calculated with dioxin and furan congeners only.

Water Body	Site Location	2002	2005	2017
Tittabawassee River	Poseyville Road			0.1
Tittabawassee River	Smiths Crossing Road	0.5		0.6
Tittabawassee River	Freeland Road	1.2		0.3
Tittabawassee River	Center Road	2.0		0.5
Saginaw River	upstream Middle Ground I	0.9	0.6	
Saginaw River	7th Street Bridge		0.7	0.3
Saginaw River	Truman Pkwy		0.8	0.5
Saginaw River	D & M RR		0.6	0.3
Saginaw River	Wilder Road		0.9	0.4
Saginaw River	River Mouth	0.9	0.6	0.4
Saginaw Bay	Gull Island			0.1

The concentrations were also consistently lower at the Saginaw River sites in 2017 as compared to the concentrations measured in 2005. Similar to the PCB concentrations, this finding may partially be explained by the difference in river discharge between the two sampling periods.

There were nominal differences in TEQ concentrations between sampling sites in 2017 but the differences were not statistically significant with two exceptions. Caged fish from the Poseyville Road site (upstream of Dow Dam on the Tittabawassee River) and the Gull Island site had net uptake of TEQ significantly less than any of the other sample sites.

Table 7. Net uptake of lipid normalized dioxin TEQ (ng/kg [ppt]). TEQ calculated with and without coplanar PCB congeners.

Water Body	Site Location	D-F TEQ	With PCBs
Tittabawassee River	Poseyville Road	0.1	NQU
Tittabawassee River	Smiths Crossing Road	0.6	0.6
Tittabawassee River	Freeland Road	0.3	0.3
Tittabawassee River	Center Road	0.5	0.5
Saginaw River	7th Street Bridge	0.3	0.4
Saginaw River	Truman Pkwy	0.5	0.6
Saginaw River	D & M RR	0.3	0.2
Saginaw River	Wilder Road	0.4	0.5
Saginaw River	River Mouth	0.4	0.5
Saginaw Bay	Gull Island	0.1	NQU

Net uptake of lipid normalized dioxin TEQ (calculated with dioxin, furan, and coplanar PCB congeners) was nearly identical to the TEQ calculated without the coplanar PCB congeners (Table 7).

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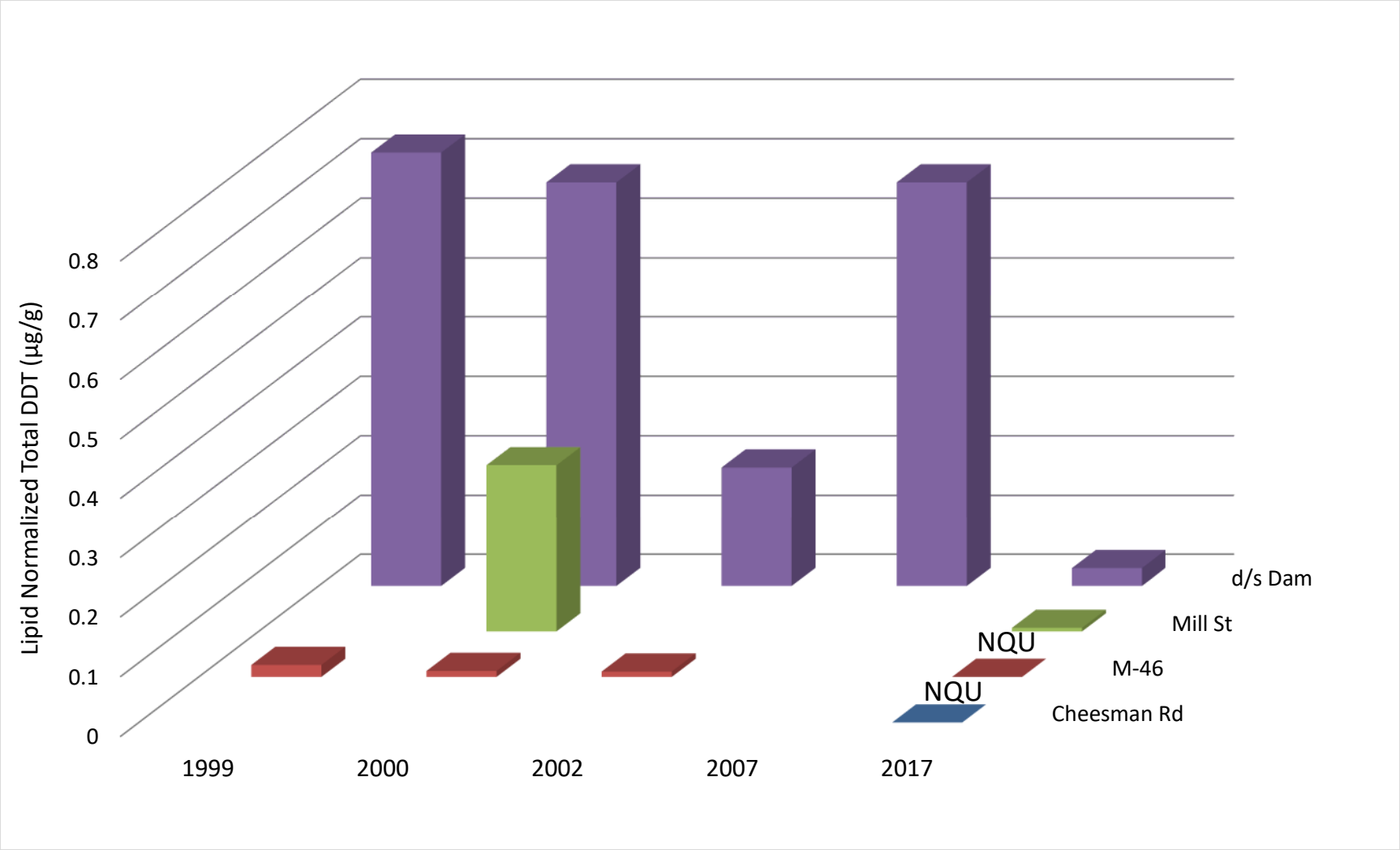

Figure 5. Net uptake of lipid normalized total DDT (µg/g [ppm]) in caged fish samples from the Pine River near St. Louis Michigan, 2017 (NQU = no quantifiable uptake).

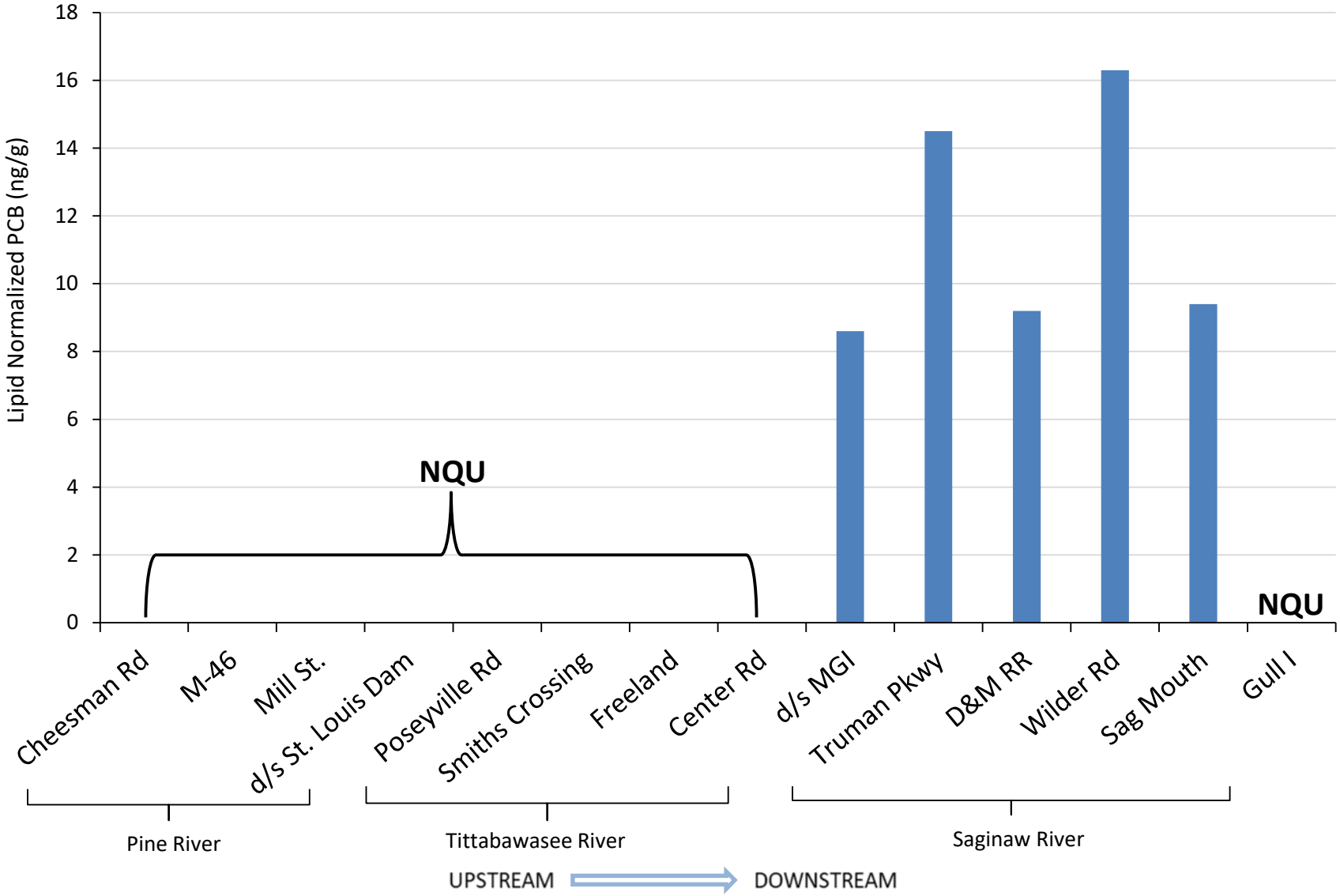

Figure 6. Net uptake of lipid normalized total PCB in the 2017 caged fish samples from the Pine, Tittabawassee, and Saginaw Rivers. NQU = no quantifiable uptake.

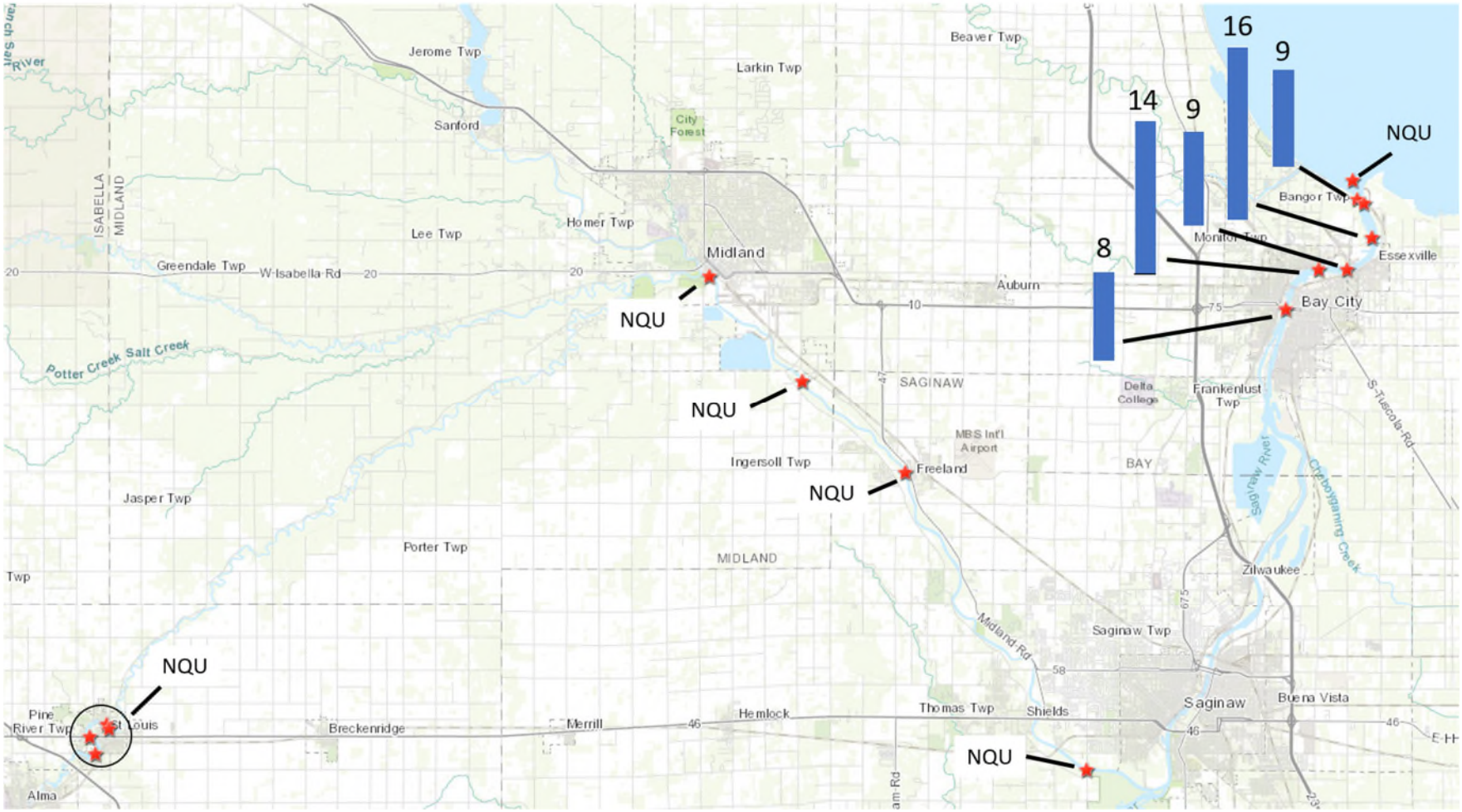

Figure 7. Net uptake of lipid normalized total PCB (ng/g [ppb]) in caged fish from the Pine, Tittabawassee, and Saginaw Rivers, 2017 (NQU = no quantifiable uptake).

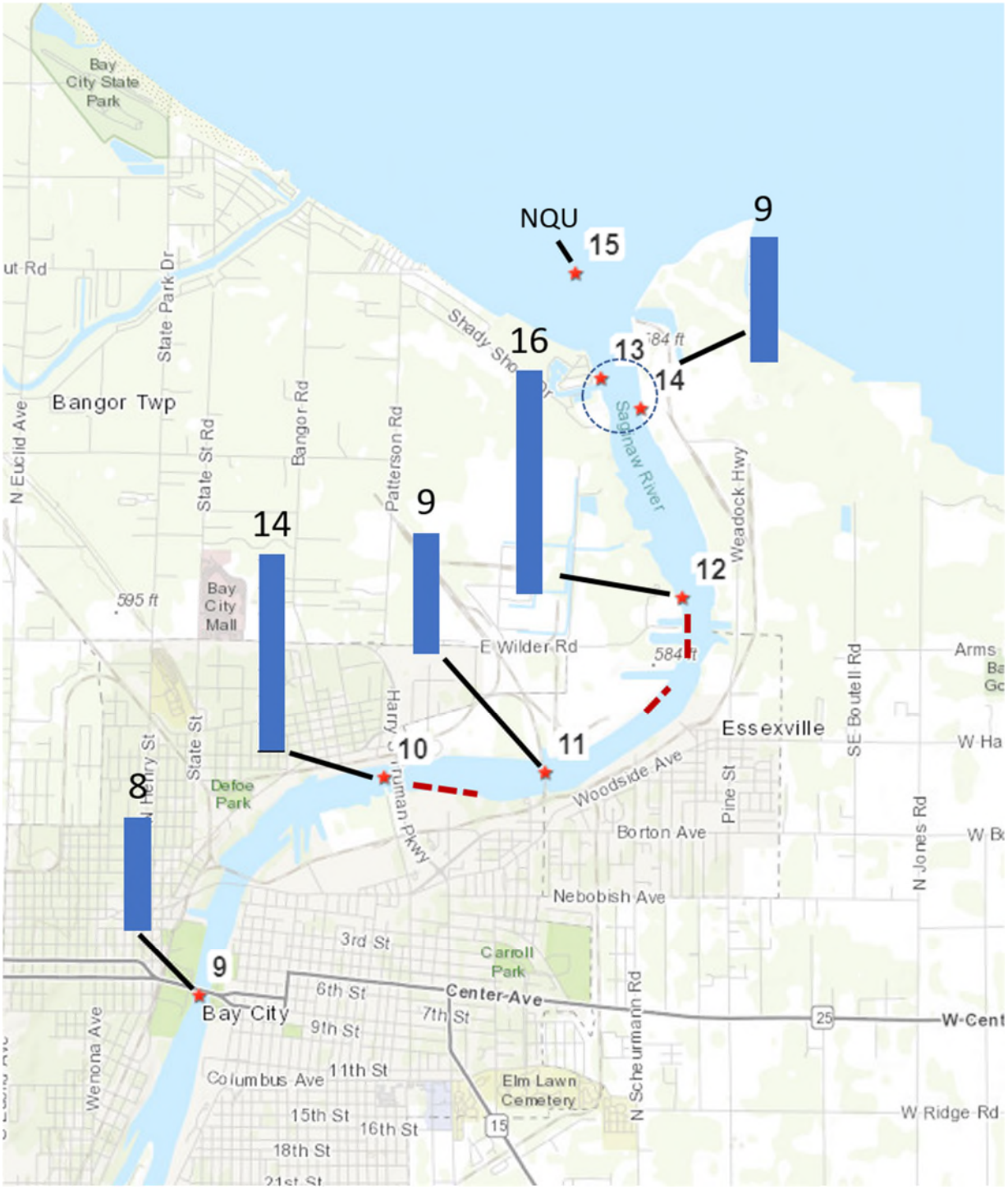

Figure 8. Net uptake of lipid normalized total PCBs (ng/g [ppb]) in caged fish from the lower Saginaw River, 2017 (NQU = no quantifiable uptake). Red dotted lines indicate approximate areas of sediment remediation completed in 2001.

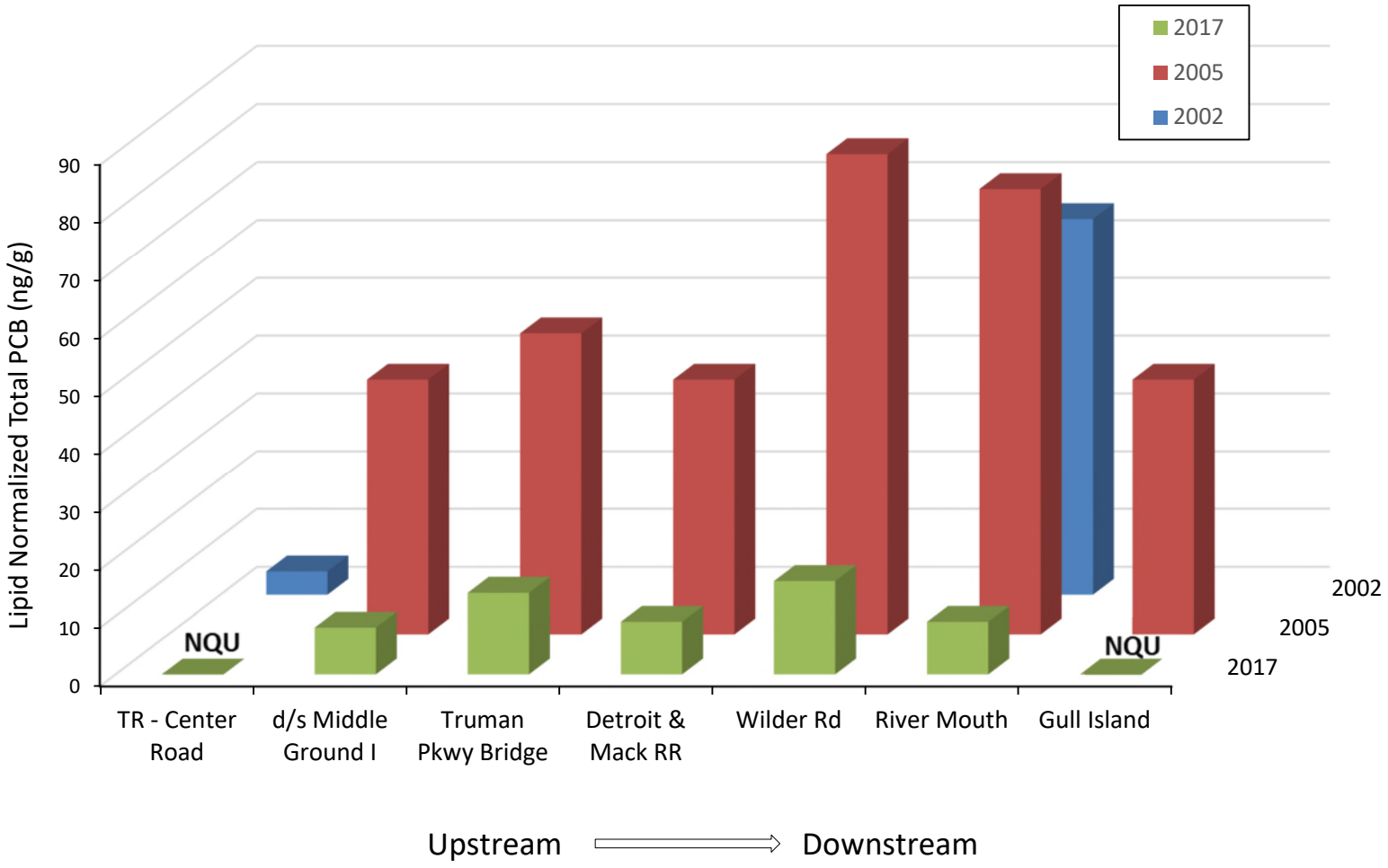

Figure 9. Net uptake of lipid normalized total PCB (ng/g [ppb]) in Saginaw River and Saginaw Bay caged fish monitored in 2002, 2005, and 2017. (NQU =No quantifiable uptake).

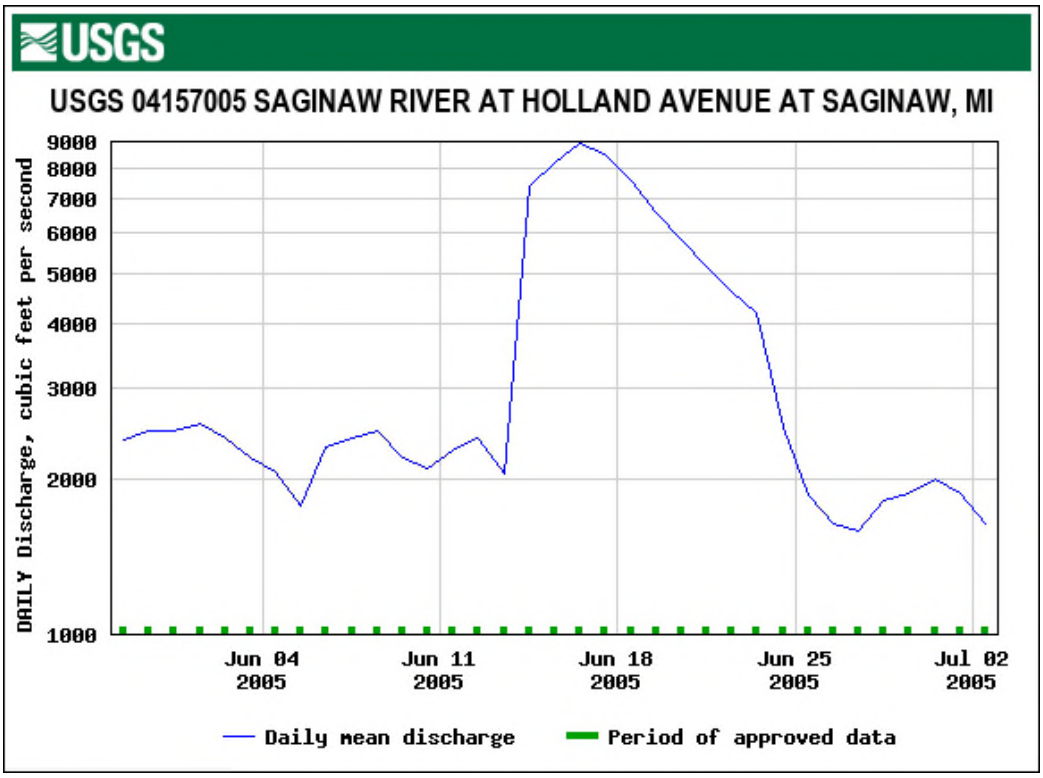

Figure 10a. Daily mean discharge of the Saginaw River at Saginaw Michigan during the 2005 caged fish sampling event.

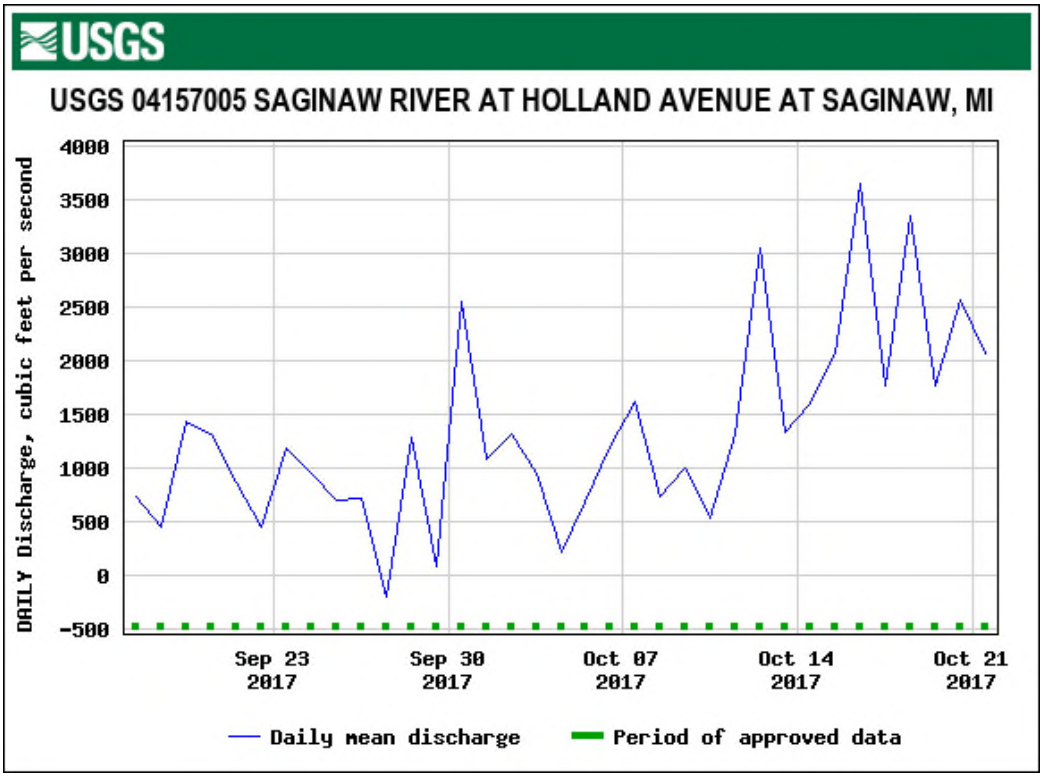

Figure 10b. Daily mean discharge of the Saginaw River at Saginaw Michigan during the 2017 caged fish sampling event.

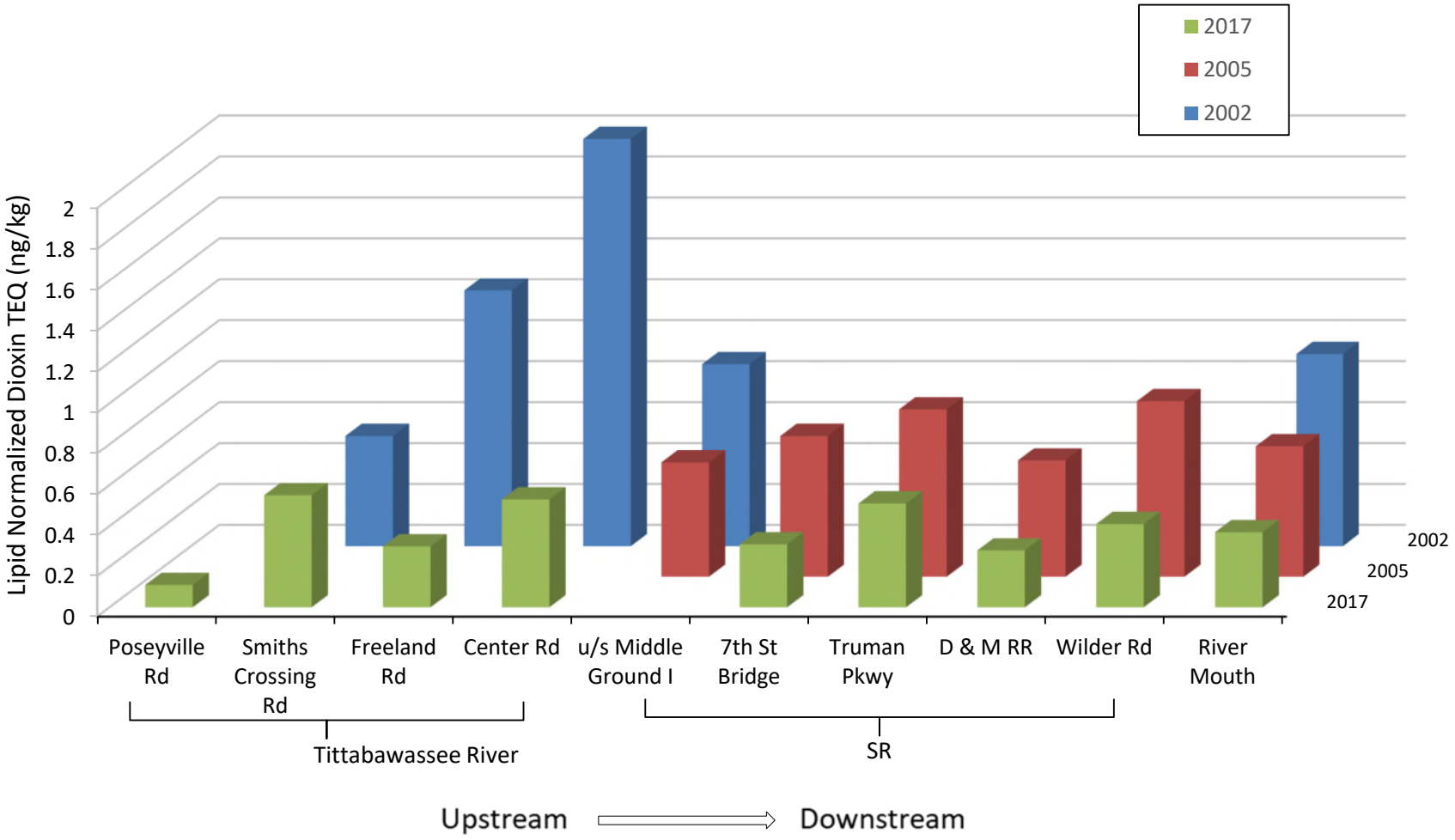

Figure 11. Net uptake of lipid normalized dioxin TEQ (ng/kg [ppt]) in Tittabawassee River and Saginaw River caged fish monitored in 2002, 2005, and 2017. TEQ calculated with dioxin and furan congeners only.

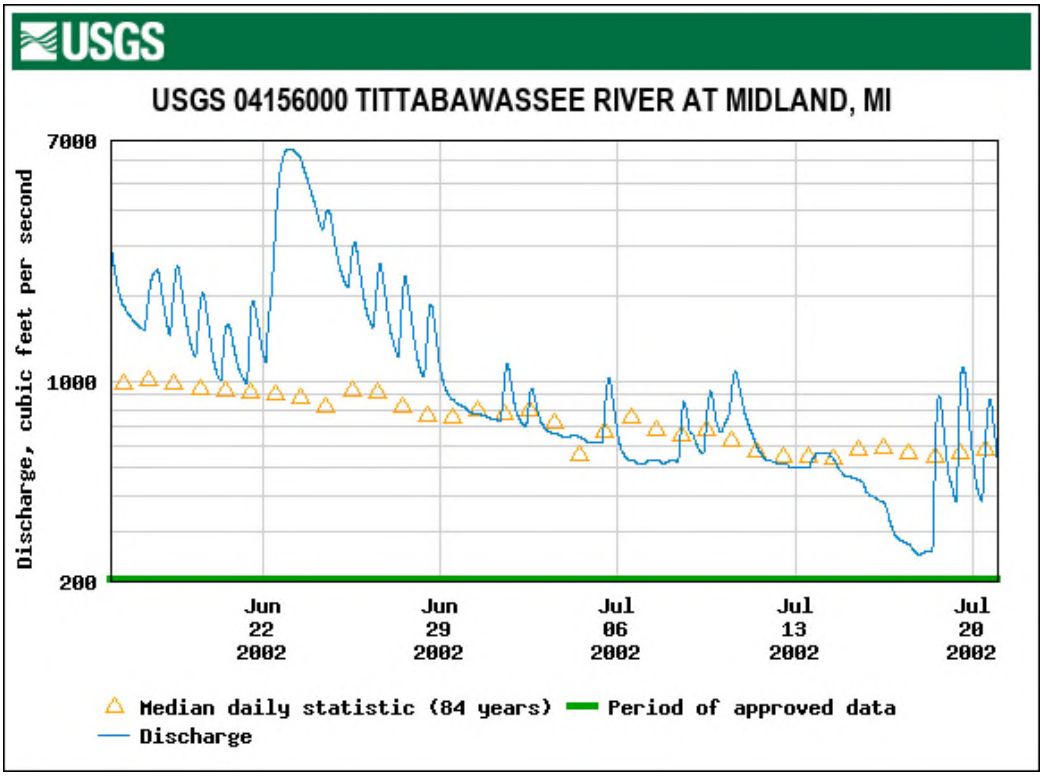

Figure 12a. Daily mean discharge of the Tittabawassee River at Midland, Michigan, during the 2002 caged fish sampling event.

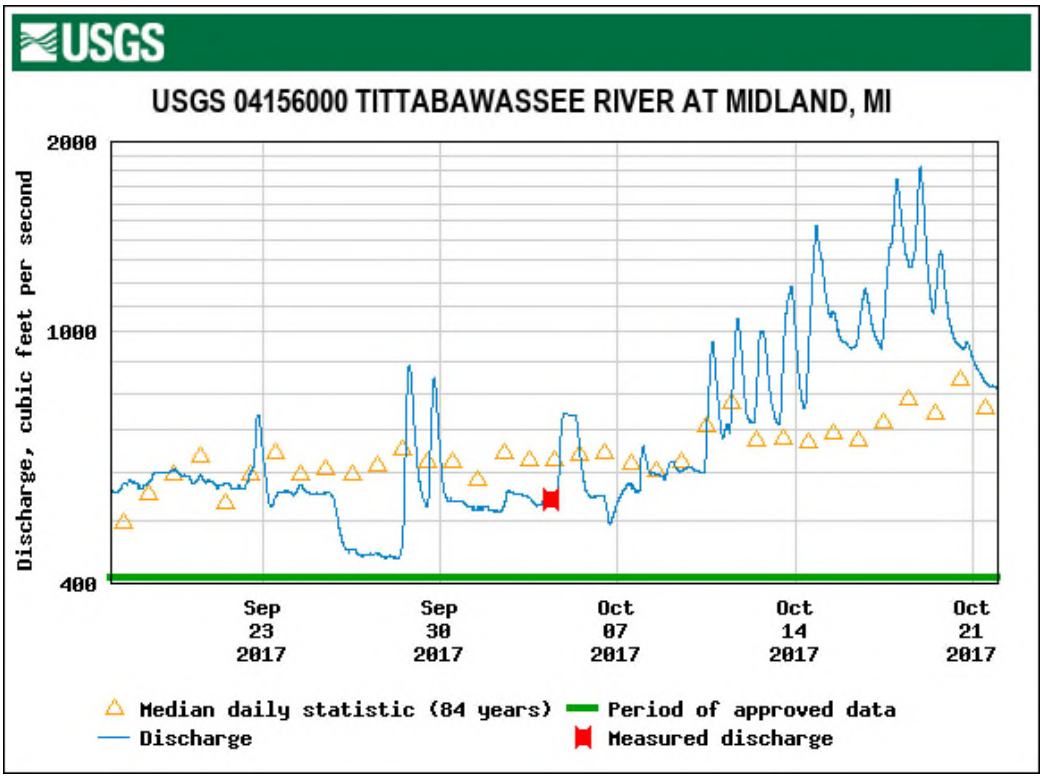

Figure 12b. Daily mean discharge of the Tittabawassee River at Midland, Michigan, during the 2017 caged fish sampling event.